Shape Coexistence Near the $N = 38$ Shell Gap. Magnetic Moment of the 119.5 keV $J^{\pi}=5/2^{-}$ level in ^{75}Br

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Extensive investigations of the structure of neutron deficient $A \approx 60-80$, $N \approx Z = 33-40$ nuclei has revealed many interesting features. Drastic changes of properties appear for nuclei with $Z \geq 33$ when going from nuclei with 50 neutrons to nuclei with 36-40 neutrons [1,2]. Large quadrupole deformations $\beta \approx 0.4$ and strong collectivity are seen. Furthermore, evidence for shape coexistence at low spins found for the first time in ^{72}Se [3] has generated a special interest in studies of the region. A striking feature is the strong variation of the shape as a function of particle number, excitation energy and spin. The microscopic structure of the nuclei from $A \approx 60-80$ mass region is essentially determined by the $2p_{1/2}$, $1f_{5/2}$, $2p_{3/2}$ and $1g_{9/2}$ orbitals. The strong shape variation and the shape coexistence effects may be interpreted as resulting from the competition of the stabilizing energy gaps of the deformed single-particle field at nucleon numbers 34, 36, 38 and 40. Calculations of the equilibrium configurations in this mass region have been performed within the configuration-dependent shell-correction approach with deformed Woods-Saxon potentials [4].

Calculations based on the generalized Woods-Saxon potential [4] (see Fig. 1., pag. 398) predict competing deformed gaps at nucleon numbers 34 and 36 for $\beta \approx -0.26$ and $\beta \approx -0.4$ respectively and at nucleon numbers 34 and 38 for $\beta \approx 0.26$ and $\beta \approx 0.4$ respectively. A pronounced shell gap also exists at a nucleon number 40 for a spherical shape. The single-particle level density in the $A \approx 60-80$ nuclei is lower by a factor of two than in deformed heavy nuclei; so, the single-particle deformed energy gaps which appear at similar nucleon numbers $(N, Z = 34-38)$ manifest themselves in a comparatively dramatic way. Hence, adding or removing a few nucleons can have a dramatic effect on the nuclear shape. Competing prolate, oblate and spherical shapes are even expected to coexist in the same nucleus. This is particularly true for the neutron-deficient selenium $(Z = 34)$ and krypton $(Z = 36)$ isotopes, where the protons appear to prefer an oblate shape but where neutron numbers of 38–42 favors a strongly deformed $\beta \approx 0.4$ prolate shape.

The shape coexistence in ^{72}Se has been explained as arising from the oblate polarizing influence of the shell gap at nucleon number 34 and the strong prolate driving influence of the gap at nucleon number 38. In recent years, nuclei near the strongly deformed shell gaps at $N = Z = 36$ and $N = Z = 38$ for large oblate and large prolate deformation, respectively, have been investigated in much detail. The recently discovered $J^{\pi} = 0^{+}$ shape isomers in ^{74}Kr and, for the first time, in the $N = Z$ nucleus ^{72}Kr reinforced the evidence of the importance of both shell gaps [5]. So, the detailed spectroscopy near the $N = 38$ deformed shell gap is still an interesting research subject.

The study of Z=35, N=40 odd-A nucleus ^{75}Br is fairly interesting, the odd proton proving the quadrupole deformation and the coexistence of different shapes of the even–even core.

Initial investigation of ^{75}Br in β-decay studies [6] established several low-spin states. Subsequent work [7,8] extended the yrast sequence up to a tentative ($25/2^{+}$) level at 3868 keV. The negative-parity yrast sequence was observed up to a tentative ($25/2^{-}$) level at 4348 keV. Significant additions to the level scheme, including lifetime measurements, were made in ^{62}Ni(^{16}O,p2n) and ^{66}Zn(^{12}C,p2n) experiments [9]. Excited states up to spin 33/2 were established for both parities. The deformations of low-lying states were deduced to fall in the range $0.28 \leq \beta \leq 0.35$. In the latest investigations using ^{58}Ni(^{24}Mg,α3p) [10] and ^{48}Ti(^{30}Si,p2n) [11] reactions states up to spins ($45/2^{+}$) and ($49/2^{-}$) were determined; a new rotational sequence with head spin-parity $9/2^{+}$ was found and a negative-parity three-quasiparticle band exhibiting rigid rotation was also discovered. These investigations established the existence of a collective decoupled band built on $J^{\pi}=9/2^{+}$ state at 221 keV. In addition to the positive-parity states a collective band built on the $J^{\pi}=3/2^{-}$ ground state was also established. This band was interpreted as a strongly coupled band built. Similar bands occur in heavier odd Se and Kr isotopes.

The magnetic moment of the ^{75}Br was measured by G. Austyn et al. [12] using low temperature nuclear orientation. A value of $\mu = +0.76(18)\mu_N$ has been obtained. Information on the low-spin and high-spin levels of ^{75}Br were recently summarized in Nuclear Data Sheets [13]. In order to obtain new information about the structure of low-spin states in ^{75}Br we intend to measure the magnetic moment of the 119.5 keV $J^{\pi}=5/2^{-}$ level ($T_{1/2}$=1.7 ns) by the time-integral perturbed angular distributions method. The shape coexistence is most obvious in the N=38 and 40 isotones of Se, and Kr. As a result of the interaction between coexisting states, the low-spin members of the ground state band do not correspond to one fixed shape but they can be treated as a mixture of well deformed (prolate) and weakly deformed (spherical or oblate) structures. Both even-mass neighbors of Br, i.e., Se and Kr, are well known as very good examples of shape isomerism.

The odd-A bromine nuclei $^{75-87}$Br with atomic number 35 are all assigned to have ground state spins of $3/2^{-}$. From Fig. 1., pag. 398 of Ref. [4] it can be seen that for for prolate deformation the 35th proton is indeed expected to occupy the $[301]3/2^{-}$ for quadrupole deformations up to $\beta<0.22$ and the $[312]3/2^{-}$ orbital at larger deformations in the range $0.30<\beta<0.40$. As these levels are associated with theoretical magnetic dipole moments of approximately $+2.3\mu_N$ and $+0.75\mu_N$, respectively, the experimental magnetic moments of the $3/2^{-}$ ground states give a clear signature of the orbitals involved and hence the magnitude of the nuclear deformation. The calculated magnetic moment for the ground state of ^{75}Br is $\mu = +(0.68\text{-}0.89)\mu_N$ [12] for prolate deformation and a $[312]3/2^{-}$ orbital configuration. The measured magnetic moment is well reproduced by the theory and is fully consistent with the deformation suggested by the electric quadrupole data. The magnetic moment is only compatible with a prolate deformation. In Fig. 1 we present the $3/2^-$ band from ^{75}Br. The behavior of the negative-parity band at spin 5/2 suggest that in ^{75}Br the $5/2^-$ level is not a member of the ground state band based on the $3/2^-$ level but the band head of a band based on $[303]5/2^-$ Nilsson orbital.

The energy of the one-quasiparticle state, characterized by K and π quantum numbers, was calculated in [9] using the usual Strutinsky method with the Woods-Saxon potential and the macroscopic energy, ELD, was assumed to be of the form of liquid drop. The pairing correction term $\delta E_{pair,\nu}$, was computed employing the standard Bardeen-Cooper-Schrieffer (BCS) treatment with blocking.

The calculations reproduce the experimentally observed level order. The ground state band head is calculated to be $3/2^-$, and the next excited state is $3/2^+$. Both of them have large prolate deformations. The other three low-lying single-particle states, $9/2^+$, $1/2^-$, (at 400 keV), and $3/2^-$ (at 560 keV) are predicted to have oblate deformations. The positive parity states have a dominating $g_{9/2}$ component, although the $d_{5/2}$ admixture to the $K^{\pi}=1/2^+$ orbital is clearly present. The negative parity states have dominating $f_{5/2}$ and $p_{3/2}$ components.

In order to obtain new information about the structure of the negative parity sequence in ^{75}Br we intend to measure the magnetic moment of the 119.5 keV $J^{\pi}=5/2^-$ level using the time-integral perturbed angular distributions method.

The experiment will be performed at the 9.0 MV Van de Graaff Tandem accelerator of NIPNE-HH. The excited states in ^{75}Br will be populated using ^{59}Co(^{19}F,p2n) reaction at 60 MeV bombarding energy. The magnetic moment of the 981.1 keV, $J^{\pi} = 8^+$ level will be measured by means of the time integral perturbed angular distribution method. This state decays to the $3/2^-$ ground state state and is not fed from higher lying states with lifetimes larger than few ps. The experimental set-up includes a special reaction chamber centered on an angular correlation turntable. In order to have the residual nuclei in a ferromagnetic environment, a thick (25μm) natural Co foil was used as a target and implantation medium. In order to saturate the internal hyperfine field, the iron foil was placed between the poles of a small electromagnet. The gamma-rays were detected by two large volume intrinsic Ge detectors, having resolutions of about 1.7 and 1.8 keV at 1.33 MeV. One of the detectors was placed at 270° and used as a monitor; the second one was placed successively at seven angles between 0° and 90°. Two measurements were performed: (a) an angular distribution measurement without polarizing magnetic field, and (b) a measurement with the moving detector placed seven angles between 0° and 90° for up and down directions of the polarizing magnetic field.

For the hyperfine field for Br nuclei in Co a value of H(Br/Co)=(615±7) kG [7] will be used.

We need 5 days (15 shifts) at the 9 MV tandem.

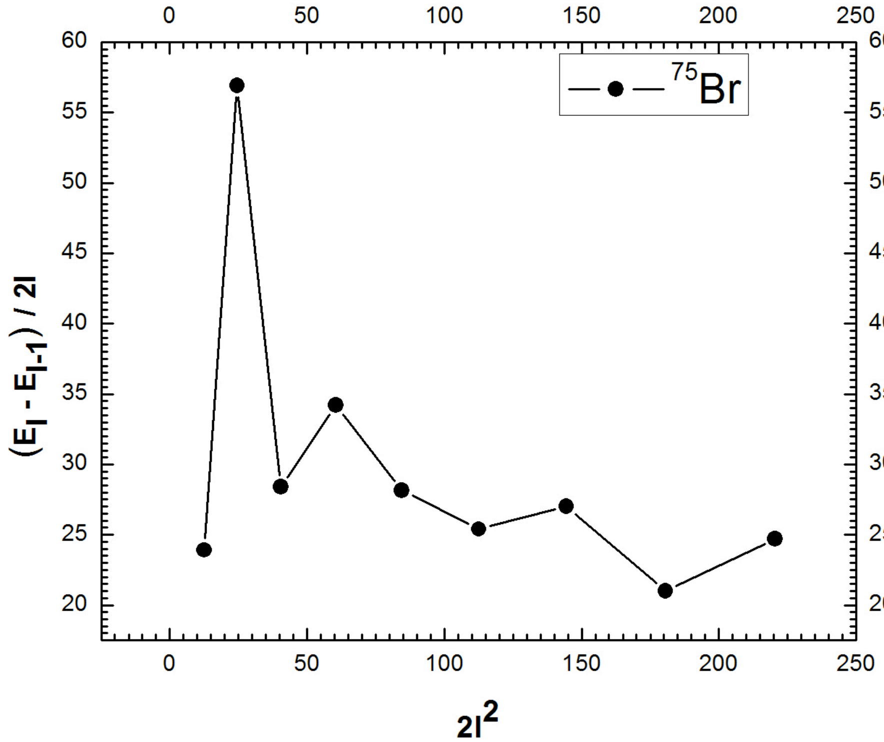

Fig.1

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